

Metric Radio Bursts and Fine Structures Observed on 17 January 2005

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Abstract

A complex radio event was observed on January 17, 2005 with the radio-spectrograph ARTEMIS-IV, operating at Thermopylae, Greece; it was associated with an X3.8 SXR flare and two fast Halo CMEs in close succession. We present ARTEMIS-IV dynamic spectra of this event; the high time resolution (1/100 sec) of the data in the 450–270 MHz range, makes possible the detection and analysis of the fine structure which this major radio event exhibits. The fine structure was found to match, almost, the comprehensive Ondrejov Catalogue which it refers to the spectral range 0.8–2 GHz, yet seems to produce similar fine structure with the metric range.

Key words: Sun: Solar flares, Sun: Radio emission, Sun: Fine Structure

1 INTRODUCTION

Radio emission at metric and longer waves trace disturbances, mainly electron beams and shock waves, formed in the process of energy release and magnetic restructuring of the corona and propagating from the low corona to interplanetary space. The fine structures, on the other hand, including drifting pulsation structures, may be used as powerful diagnostics of the loop evolution of solar flares.

The period 14–20 January 2005 was one of intense activity originating in active regions 720 and 718; while in the visible hemisphere of the sun,

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they produced 5 X-class and 17 M-class flares, an overview is presented in Bouratzis et al. (2006).

January the 17th is characterized by an X3.8 SXR flare from 06:59 UT to 10:07 UT (maximum at 09:52 UT) and two fast Halo CMEs within a forty minute interval. The corresponding radio event included an extended broadband continuum with rich fine structure; this fine structure is examined in this report.

2 Observations

2.1 Instrumentation

The Artemis IV¹ solar radio-spectrograph operating at Thermopylae since 1996 (Caroubalos et al., 2001b; Kontogeorgos et al., 2006a) consists of a 7-m parabolic antenna covering the metric range, to which a dipole antenna was added recently in order to cover the decametric range. Two receivers operate in parallel, a sweep frequency analyzer (ASG) covering the 650-20 MHz range in 630 data channels with a cadence of 10 samples/sec and a high sensitivity multi-channel acousto-optical analyzer (SAO), which covers the 270-450 MHz range in 128 channels with a high time resolution of 100 samples/sec.

Events observed with the instrument have been described, e.g. by Caroubalos et al. (2004, 2001a), Kontogeorgos et al. (2006b, 2008), Bouratzis et al. (2006), Petoussis et al. (2006), cf. also Caroubalos et al. (2006) for a brief review.

The broad band, medium time resolution recordings of the ASG are used for the detection and analysis of radio emission from the base of the corona to two R_{SUN} , while the narrow band, high time resolution SAO recordings are mostly used in the analysis of the fine temporal and spectral structures.

2.2 The event of January 17, 2005–Overview

Two groups of type III bursts and a very extensive type IV continuum with rich fine structure characterize the ARTEMIS–IV dynamic spectrum. The high frequency type IV emission starts at 08:53 UT, covers the entire 650-20MHz ARTEMIS–IV spectral range (Figure 1, upper & middle panels) and continues

¹ Appareil de Routine pour le Traitement et l' Enregistrement Magnetique de l' Information Spectral

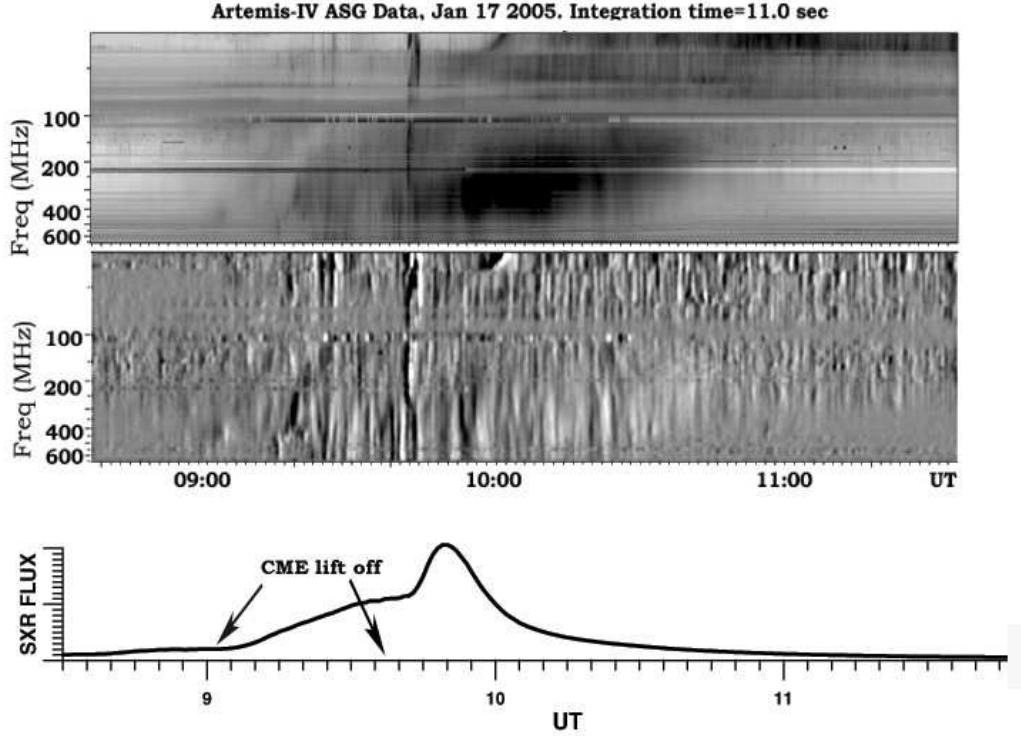


Fig. 1. ARTEMIS IV Dynamic Spectrum (08:40-11:30 UT). UPPER PANEL: ASG Spectrum, MIDDLE PANEL: ASG Differential Spectrum, LOWER PANEL: GOES SXR flux (arbitrary units); the two CME lift-offs are marked on the time axis.

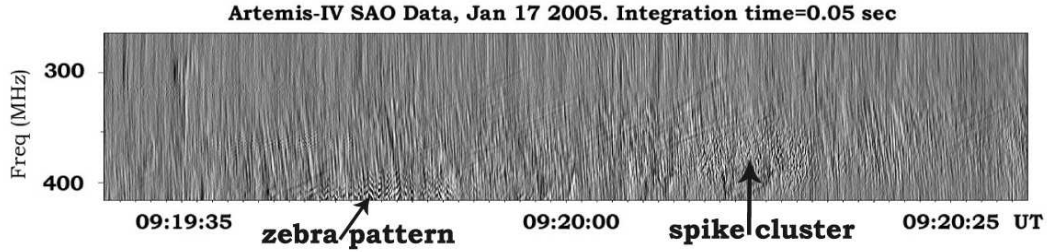


Fig. 2. ARTEMIS IV SAO Differential Spectrum: Zebra pattern (09:19:40-09:19:52 UT) and a spike cluster (09:20:08-09:20:15) on a background of fiber bursts & pulsations (09:19:30-09:20:30 UT); the pulsations with the fibers cover the observation period but they appear more pronounced in the 09:35-09:55 UT interval.

well after 15:00; it was associated with an SXR flare and two fast Halo CMEs (CME₁ & CME₂ henceforward) in close succession.

The GOES records² report an X3.8 SXR flare from 06:59 UT to 10:07 UT, with maximum at 09:52 UT; this is well associated with the brightening of sheared S-shaped loops from the EIT images. The SXR light curve (Figure

² <http://www.sel.noaa.gov/ftpmenu/indices>

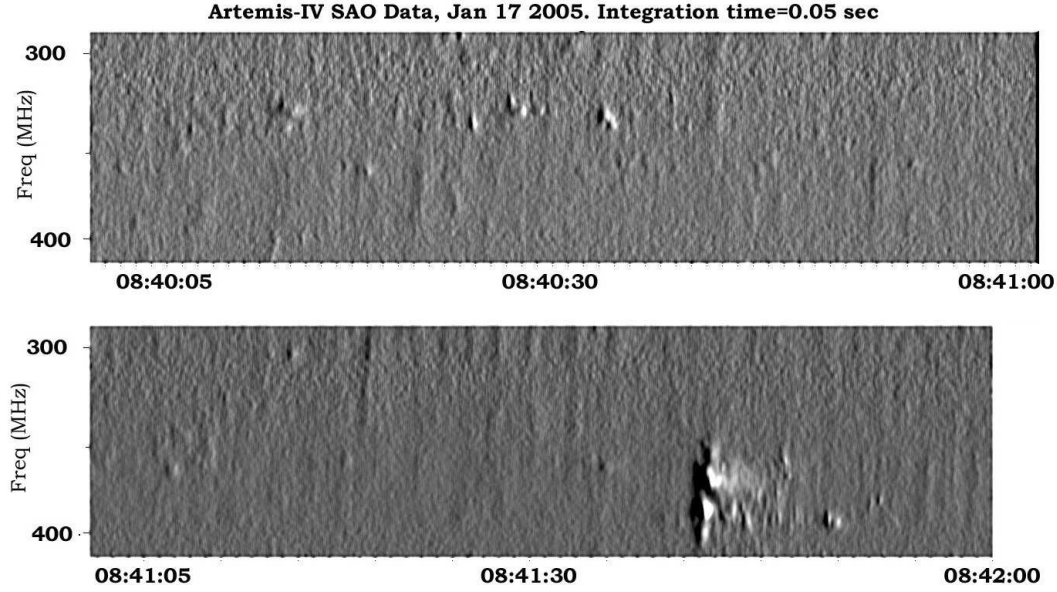


Fig. 3. ARTEMIS IV Differential Spectra of Fine Structures embedded in the Type IV Continuum. UPPER PANEL: Spikes, LOWER PANEL: Narrow Band Type III(U) Bursts.

1, lower panel) exhibits an, initially, slow rising phase which changes into a much faster rising a little before the peak flux is reached; it thus appears on the time–SXR flux diagram as a two stage process. The CME data from the LASCO lists on line³ (Yashiro et al., 2004) indicate that each of the stages coincides with the, estimated, lift off time of CME₁ & CME₂ respectively; its also well associated with the high frequency onset of the two type III groups mentioned in the beginning of this subsection. The *halo* CME₁ was first recorded by LASCO at 09:30:05 UT. Backward extrapolation indicates that it was launched around 09:00:47 UT. CME₂ was first recorded by LASCO at 09:54 UT; it was launched around 09:38:25 UT and was found to overtake CME₁ at about 12:45 UT at a height of approximate 37 solar radii.

2.3 Fine Structure

The high sensitivity and time resolution of the SAO facilitated an examination on fine structure embedded in the Type–IV continua within the studied period. In our analysis, the continuum background is removed by the use of high–pass filtering on the dynamic spectra (differential spectra in this case).

As fine structure is characterized by a large variety in period, bandwidth, amplitude, temporal and spatial signatures, a morphological taxonomy scheme

³ http://cdaw.gsfc.nasa.gov/CME_list

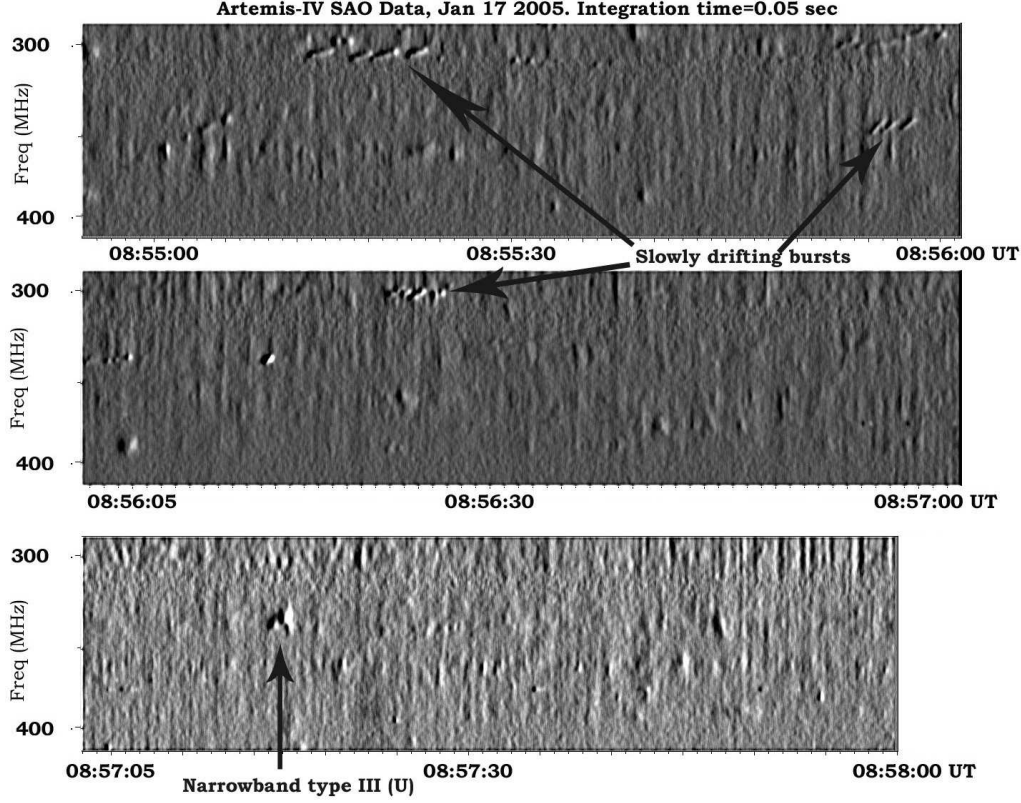


Fig. 4. ARTEMIS IV Differential Spectra of Fine Structures embedded in the Type IV Continuum. FIRST TWO PANELS: Narrow Band Slowly Drifting Bursts LOWER PANEL: Narrow Band Type III(U).

based on Ondrejov Radiospectrograph recordings in the 0.8–2.0 GHz range was introduced (Jiříčka et al. (2001, 2002) also Mészárosová et al. (2005)); the established classification criteria are used throughout this report.

We present certain examples of fine structures recorded by the ARTEMIS–IV/SAO in the 450–270 MHz frequency range; this range corresponds to ambient plasma densities which are typical of the base of the corona ($\approx 10^9 \text{ cm}^{-3}$, (cf. for example Mann et al., 1999). The fine structures of our data set, are divided according to the above mentioned Ondrejov classification scheme and described in the following paragraphs (cf. also figures 2, 3, 4 & 5).

2.3.1 Broadband pulsations & Fibers

The broadband pulsations appear for the duration of the type IV continuum; they are, for same period, associated with fibers; these structures intensify within the rise phase of the SXR, which in turn, coincides with the extrapolated liftoff of CME₁ & CME₂. Follows a closer examination:

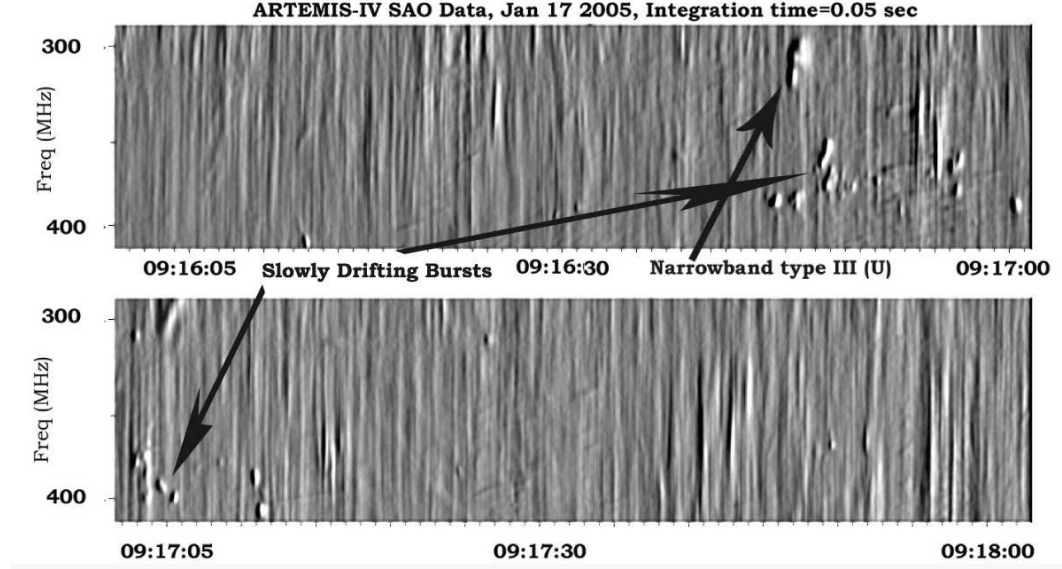


Fig. 5. ARTEMIS IV Differential Spectra of Fine Structures embedded in the Type IV Continuum; narrowband bursts within groups fiber bursts & pulsating structures: UPPER PANEL: Narrowband Type III(U), Narrow Band Slowly Drifting Bursts & spikes; LOWER PANEL: Narrow Band Slowly Drifting Burst & spikes.

- Radio pulsations are series of pulses with bandwidth $> 200\text{MHz}$ and total duration $> 10\text{s}$; on the ARTEMIS-IV recordings they persisted for the duration of the type IV continuum. Some, with a slow global frequency drift, were of the *Drifting Pulsation Structures* (DPS) subcategory. In our recordings the pulsations bandwidth exceeded the SAO frequency range, however from the ASG dynamic spectrum we observe a drift of the pulsating continuum towards the lower frequencies, following the rise of CME₂. Three physical mechanisms were proposed as regards the source of this type of structure, (cf Nindos and Aurass (2007) for a review):

- Modulation of radio emission by MHD oscillations in a coronal loop
- Non-linear oscillating systems (wave-wave or wave particle interactions) where the pulsating structure corresponds to their limit cycle
- Quasi-periodic injection of electron populations from acceleration episodes within large scale current sheets.

Combined radiospectrograph, radio and SXR imaging and HXR observations (Kliem et al., 2000; Khan et al., 2002; Karlický et al., 2002) favor the last mechanism; furthermore they identify the sources of Drifting Pulsation Structures with plasmon ejections.

- Isolated Broadband Pulses: Pulsating Structures but with duration $\approx 10\text{s}$.
- Fast Drifting Bursts: Short-lasting and fast drifting bursts with frequency drift $> 100\text{MHz/s}$; similar to the isolated broadband pulses, except for the frequency drift.
- Fibers or Intermediate Drift Bursts: Fine structure Bursts with the frequency drift $\approx 100\text{MHz/s}$; they often exhibit nearly regular repetition.

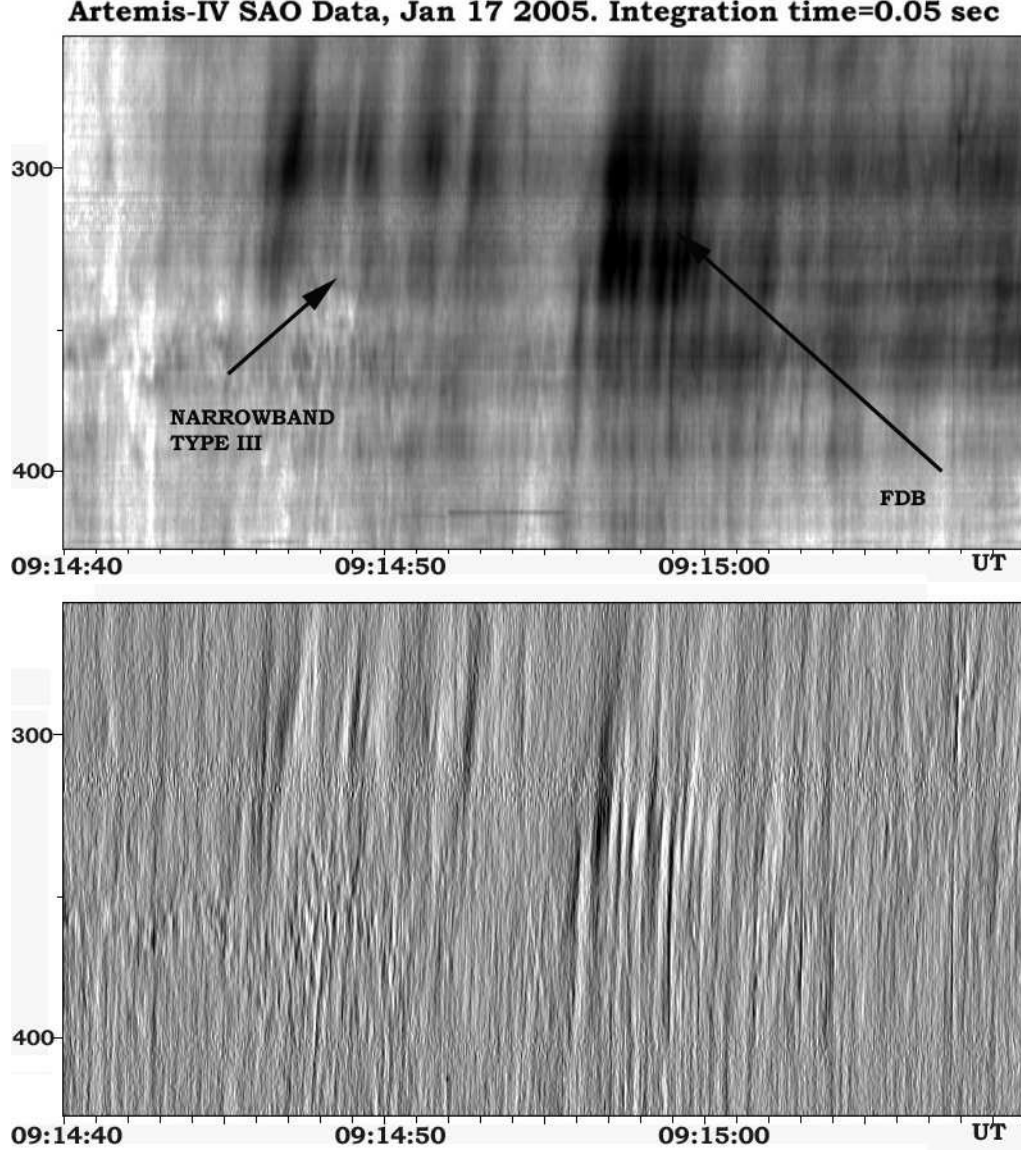


Fig. 6. ARTEMIS IV Spectra of Fast Drift Bursts (FDB), 09:14:55-09:15:00 UT, preceded by narrowband type III bursts. UPPER PANEL: Intensity Spectrum LOWER PANEL: Differential Spectrum.

On our recordings they coincide with broadband pulsations and they also cover the duration of the type IV continuum. They are usually interpreted as the radio signature of whistler waves coalescence with Langmuir waves in magnetic loops; the exciter is thought to be an unstable distribution of nonthermal electrons. (cf. Nindos and Aurass (2007) and references within).

2.3.2 Zebra patterns:

The zebra structures are characterized by several emission lines, which maintain nearly regular distance to their neighbors (figure 2). The zebras

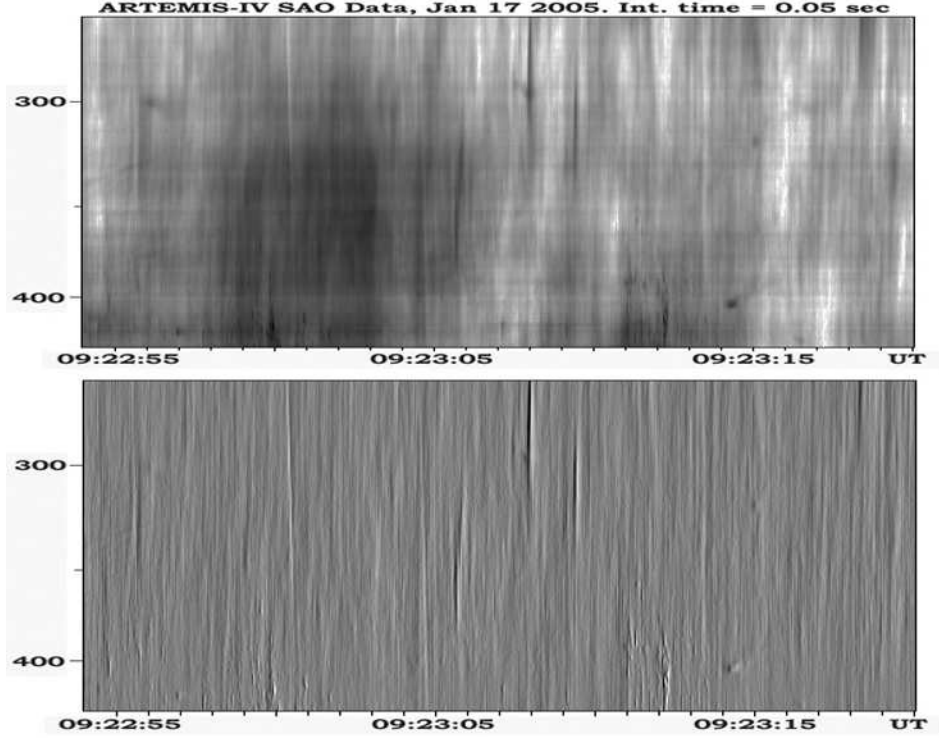


Fig. 7. ARTEMIS IV Spectra of Isolated Pulsating Structures (IPS), 09:22:55-09:23:05 UT. UPPER PANEL: Intensity Spectrum LOWER PANEL: Differential Spectrum.

from our data set are associated with pulsations and fibers and cover almost the same period with them. They appear, however, more pronounced in the 09:35–09:55 UT interval; this interval includes the CME_2 estimated launch and the rise phase of the SXR flare. Zebra patterns were explained as the result electrostatic upper-hybrid waves at conditions of the double plasma resonance where the local upper hybrid frequency equals a multiple of the local gyrofrequency ($\omega_{UH} = \sqrt{\omega_e^2 + \omega_{Be}^2} = s \cdot \omega_{Be}$) (cf. for example Chernov et al. (2006); Nindos and Aurass (2007) and references therein). The upper hybrid waves are excited by electron beam with loss-cone distribution (Kuznetsov and Tsap, 2007).

2.3.3 Narrowband Structures

The narrowband activity (figures 3, 4 & 5), including Spikes, Narrow Band Type III & III(U) bursts as well as Slowly Drifting Structures, is rather intermittent. A large group of spikes appears at about 09:20 UT; this coincides, in time, with the rising of the first stage of the SXR and the start of the first type III group. Three types of Narrowband Structures were recorded:

- Narrow Band Spikes are very short ($\approx 0.1s$) narrowband ($\approx 50MHz$) bursts which usually appear in dense clusters. An example of such a cluster appears on figure 2. The models proposed for the spike interpretation are based either on the loss-cone instability of trapped electrons producing electron cyclotron maser emission or on upper-hybrid and Bernstein modes. An open question remains whether or not spikes are signatures of particle accelerations episodes at a highly fragmented energy release flare site.
- Narrow Band Type III Bursts: Short ($\approx 1s$) narrowband ($< 200MHz$) fast drifting ($> 100MHz/s$) bursts. A number of this type of Bursts, on the SAO high resolution dynamic spectra, exhibit a frequency drift turn over; as they drift towards lower frequencies and after reaching a minimum frequency (*turn over frequency*) they reverse direction towards higher frequencies appearing as inverted U on the dynamic spectra. These we have marked as narrowband type III(U) on figures 3, 4 & 5. Similar spectra (III(U), III(N)) were obtained in the microwave range by Fu et al. (2004).
- Narrow Band Slowly Drifting Bursts: They are similar to Narrow Band Type III Bursts but with a drift rate $< 100MHz/s$.

3 Summary and Discussion

The ARTEMIS-IV radio-spectrograph, operating in the range of 650-20 MHz, observed a number of complex events during the super-active period of period 14–20 January 2005; the event on January the 17th was characterized by an extended, broadband type IV continuum with rich fine structure.

We have examined the morphological characteristics of fine structure elements embedded in the continuum; it, almost, matches the comprehensive Ondrejov Catalogue (Jiříčka et al., 2001, 2002). The latter, although it refers to the spectral range 0.8–2 GHz, seems to produce similar fine structure with the metric range.

The high resolution (100 samples/sec) SAO recordings facilitated the spectral study of the fine structures and permitted the recognition and classification of the type III(U) & III(J) subcategory of the Narrow Band Type III Bursts in the metric frequency range; similar structures have been reported in the microwaves (Fu et al., 2004).

The pulsating structures and fibers, although they cover the full observation interval, appear enhanced during the SXR rise phase and the two CME lift off where the major magnetic restructuring takes place. The narrowband structures, on the other hand, are evenly distributed for the above mentioned duration; this indicates that small electron populations are accelerated even after the flare impulsive phase.

Two types of fine structures from the Ondrejov Catalogue were not detected in our recordings:

- Continua: As the long duration pulsations accompanied by fibers were prevalent in the SAO spectra, any possible appearance of Continua was, probably, suppressed within the pulsating background.
- Lace Pattern: It is new type of fine structure first reported by Jiříčka et al. (2001); it is characterized by rapid frequency variations, both positive and negative. It is a very rare structure with only nine reported in the Ondrejov catalog out of a total of 989 structures.

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References

- Bouratzis, K., Preka-Papadema, P., Hillaris, A., Moussas, X., Caroubalos, C., Petoussis, V., Tsitsipis, P., Kontogeorgos, A., Radio Bursts in the Active Period January 2005. In: Solomos, N. (Ed.), Recent Advances in Astronomy and Astrophysics. Vol. 848 of American Institute of Physics Conference Series. pp. 213–217, 2006.
- Caroubalos, C., Alissandrakis, C. E., Hillaris, A., Nindos, A., Tsitsipis, P., Moussas, X., Bougeret, J.-L., Bouratzis, K., Dumas, G., Kanellakis, G., Kontogeorgos, A., Maroulis, D., Patavalis, N., Perche, C., Polygiannakis, J., Preka-Papadema, P., ARTEMIS IV Radio Observations of the 14 July 2000 Large Solar Event. *Sol. Phys.*204, 165–177, 2001a.
- Caroubalos, C., Maroulis, D., Patavalis, N., Bougeret, J.-L., Dumas, G., Perche, C., Alissandrakis, C., Hillaris, A., Moussas, X., Preka-Papadema, P., Kontogeorgos, A., Tsitsipis, P., Kanelakis, G., The New Multichannel Radiospectrograph ARTEMIS-IV/HECATE, of the University of Athens. *Experimental Astronomy* 11, 23–32, 2001b.
- Caroubalos, C., Hillaris, A., Bouratzis, C., Alissandrakis, C. E., Preka-Papadema, P., Polygiannakis, J., Tsitsipis, P., Kontogeorgos, A., Moussas, X., Bougeret, J.-L., Dumas, G., Perche, C., Solar type II and type IV radio bursts observed during 1998-2000 with the ARTEMIS-IV radiospectrograph. *A&A*413, 1125–1133, 2004.

- Caroubalos, C., Alissandrakis, C. E., Hillaris, A., Preka-Papadema, P., Polygiannakis, J., Moussas, X., Tsitsipis, P., Kontogeorgos, A., Petoussis, V., Bouratzis, C., Bougeret, J.-L., Dumas, G., Nindos, A., Ten Years of the Solar Radiospectrograph ARTEMIS-IV. In: Solomos, N. (Ed.), *Recent Advances in Astronomy and Astrophysics*. Vol. 848 of American Institute of Physics Conference Series. pp. 864–873, 2006.
- Chernov, G. P., Sych, R. A., Yan, Y., Fu, Q., Tan, C., Huang, G., Wang, D.-Y., Wu, H., Multi-Site Spectrographic and Heliographic Observations of Radio Fine Structure on April 10, 2001. *Sol. Phys.* 237, 397–418, 2006.
- Fu, Q.-J., Yan, Y.-H., Liu, Y.-Y., Wang, M., Wang, S.-J., A New Catalogue of Fine Structures Superimposed on Solar Microwave Bursts. *Chinese Journal of Astronomy and Astrophysics* 4, 176–188, 2004.
- Jiříčka, K., Karlický, M., Mészárosová, H., Snízek, V., Global statistics of 0.8–2.0 GHz radio bursts and fine structures observed during 1992–2000 by the Ondřejov radiospectrograph. *A&A* 375, 243–250, 2001.
- Jiříčka, K., Karlický, M., Mészárosová, H., Occurrences of different types of 0.8–2.0 GHz solar radio bursts and fine structures during the solar cycle. In: Sawaya-Lacoste, H. (Ed.), *Solspa 2001, Proceedings of the Second Solar Cycle and Space Weather Euroconference*. Vol. 477 of ESA Special Publication. pp. 351–354, 2002.
- Karlický, M., Fárník, F., Mészárosová, H., High-frequency slowly drifting structures in solar flares. *A&A* 395, 677–683, 2002.
- Khan, J. I., Vilmer, N., Saint-Hilaire, P., Benz, A. O., The solar coronal origin of a slowly drifting decimetric-metric pulsation structure. *A&A* 388, 363–372, 2002.
- Kliem, B., Karlický, M., Benz, A. O., Solar flare radio pulsations as a signature of dynamic magnetic reconnection. *A&A* 360, 715–728, 2000.
- Kontogeorgos, A., Tsitsipis, P., Caroubalos, C., Moussas, X., Preka-Papadema, P., Hillaris, A., Petoussis, V., Bouratzis, C., Bougeret, J.-L., Alissandrakis, C. E., Dumas, G., The improved ARTEMIS IV multichannel solar radio spectrograph of the University of Athens. *Experimental Astronomy* 21, 41–55, 2006a.
- Kontogeorgos, A., Tsitsipis, P., Moussas, X., Preka-Papadema, G., Hillaris, A., Caroubalos, C., Alissandrakis, C., Bougeret, J.-L., Dumas, G., Observing the Sun at 20 650 MHz at Thermopylae with Artemis. *Space Sci. Rev.* 122, 169–179, 2006b.
- Kontogeorgos, A., Tsitsipis, P., Caroubalos, C., Moussas, X., Preka-Papadema, P., Hillaris, A., Petoussis, V., Bougeret, J.-L., Alissandrakis, C. E., Dumas, G., Measuring solar radio bursts in 20650 MHz. *Measurement* 41, 251–258, 2008.
- Kuznetsov, A. A., Tsap, Y. T., Double plasma resonance and fine spectral structure of solar radio bursts. *Advances in Space Research* 39, 1432–1438, 2007.
- Mann, G., Jansen, F., MacDowall, R. J., Kaiser, M. L., Stone, R. G., A heliospheric density model and type III radio bursts. *A&A* 348, 614–620, 1999.

- Mészárosová, H., Rybák, J., Zlobec, P., Magdalenic, J., Karlický, M., Jiříčka, K., Statistical Analysis of Pulsations and Pulsations with Fibers in the Range 800-2000 MHz. In: The Dynamic Sun: Challenges for Theory and Observations. Vol. 600 of ESA Special Publication. pp. 133–136, 2005.
- Nindos, A., Aurass, H., Pulsating Solar Radio Emission. In: Klein, K.-L., MacKinnon, A. L. (Eds.), Lecture Notes in Physics, Berlin Springer Verlag. Vol. 725 of Lecture Notes in Physics, Berlin Springer Verlag. pp. 251–277, 2007.
- Petoussis, V., Tsitsipis, P., Kontogeorgos, A., Moussas, X., Preka-Papadema, P., Hillaris, A., Caroubalos, C., Alissandrakis, C. E., Bougeret, J.-L., Dumas, G., Type II and IV radio bursts in the active period October-November 2003. In: Solomos, N. (Ed.), Recent Advances in Astronomy and Astrophysics. Vol. 848 of American Institute of Physics Conference Series. pp. 199–206, 2006.
- Yashiro, S., Gopalswamy, N., Michalek, G., St. Cyr, O. C., Plunkett, S. P., Rich, N. B., Howard, R. A., A catalog of white light coronal mass ejections observed by the SOHO spacecraft. J. Geophys. Res.109 (18), 7105, 2004.